Toward an Adequate Method to Isolate Spectroscopic Families of Diffuse Interstellar Bands

B.Wszołek[1],[2] & W. Godłowski[2]

1.Wyższa Szkoła Pedagogiczna, ul Armi Krajowej 13/15, 42-200 Częstochowa, Poland.
2.Obserwatorium Astronomiczne Uniwersytetu Jagiellońskiego, ul. Orla 171, 30-244 Kraków, Poland
(E-mail:bogdan@wsp.czest.pl & godlows@oa.uj.edu.pl)

ABSTRACT
We divide some of the observed diffuse interstellar bands (DIBs) into families which appear to have spectral structures of single species. Three different methods are applied to separate such families, exploring the best approach for future investigations of this type. Starting with statistical treatment of the data, we found that statistical methods by themselves give insufficient results. Two other methods of data analysis ("Averaging EWs" and "Investigating the figures with arranged spectrograms") were found to be more useful as tools for finding the spectroscopic families of DIBs. On the basis of these methods, we suggest some candidates as "relatives" of 5780 and 5797 bands.

Key words: interstellar matter, diffuse interstelar bands

1 INTRODUCTION

Diffuse interstellar bands (see e.g. Herbig 1995), absorption structures of interstellar origin still await explanation. The identification of the carrier(s) of DIBs is one of the most difficult challenges for spectroscopists.

To the present day, huge amounts of observational data on DIBs have been stored by astronomers and published in hundreds of papers. Unfortunately, astronomical data still do not meet sufficient understanding from the point of view of laboratory spectroscopists.

One tries, in general, to solve the mystery of the carrier(s) of DIBs on the field of interdisciplinary spectroscopic collaboration between molecular physicists, molecular chemists and astronomers. One expects that some progress on this field will be possible when all known DIBs (about three hundred of them have been discovered in visible light region) are divided into families in such a way that only one carrier is responsible for all bands belonging to a given family. Such families of bands we call 'spectroscopic' ones, to distinguish them from 'characterological' families isolated by the other authors (Chlewicki et.al. 1986, Krełowski & Walker 1987, Josafatson & Snow 1987). All bands belonging to the spectroscopic family are, by definition, caused by the same carrier. Bands belonging to the characterological family have some common characteristics (e.g. all are rather narrow), but they may be produced by different carriers.

To isolate spectroscopic families of bands, first of all one has to by-pass in some way the problem of the "noisy correlation". In a given spectrogram we have to deal with a complicated mixture of interstellar absorption structures. This is because the medium between the target star and the observer contains various species. For different directions (various target stars) we have to deal with different column densities of interstellar matter giving contributions to the spectra. Intensities of all spectral lines (bands) measured in a spectrogram are well correlated with the column density of relevant matter and therefore also lines originated by different species are mutually correlated. Such correlation we call "noisy correlation". Of course not only differences in column densities of relevant interstellar matter may produce noisy correlation between DIBs. Other contribution to correlation of this kind may be given, for example, by mutually dependent astrochemical processes. Noisy correlation tells us nothing about spectroscopic families of bands.

The number of recognized DIBs has grown dramatically in recent years, primarily due to better quality of observational material. More and more weak DIBs (WDIBs) seem to appear every time a given spectral region is analysed carefully. One of the authors of this paper (BW) spent a few years analysing spectra for new, very weak DIBs. It turned out to be of great importance to reexamine the problem of DIB families. The aim of this paper is to explore further the properties of DIBs in the context of isolating families of the structures. We first describe observational material which revealed the above mentioned absorption bands. Then we present the results of the measuring procedure and describe DIB searching methods. In the last section of the paper we discuss the problem of some adequate method for separating spectroscopic families of DIBs, and we pick out two probable "relatives" for 5780 band and four other ones for 5797 band.

L / HD	6065	6090	6113	6196	6203	6234	6270	6376	6379	6426	6439	6521	6614	6661	6699	5780	5797	5850
13267	6 / 1 / 15	7 / 3 / 16	5 / 3 / 11					24 / 3 / 30	48 / 3 / 72	6 / 3 / 21		18 / 1 / 26	107 / 4 / 111	24 / 6 / 30		275 / 10 / 117	69 / 4 / 69	23 / 3 / 28
14489	9 / 2 / 13	11 / 1 / 18	23 / 2 / 25					39 / 9 / 37	36 / 3 / 58	9 / 1 / 23		14 / 1 / 23	103 / 3 / 98	53 / 4 / 49	30 / 4 / 23	274 / 10 / 154	77 / 4 / 77	24 / 3 / 32
21389	8 / 2 / 14	8 / 3 / 14	17 / 4 / 16					29 / 2 / 40	56 / 6 / 73	7 / 2 / 24		19 / 2 / 28	160 / 3 / 151	58 / 3 / 65	40 / 3 / 34	413 / 10 / 195	99 / 5 / 96	26 / 4 / 40
22951	1 / 1 / 3	6 / 2 / 12	7 / 2 / 8	17 / 2 / 32	38 / 5 / 26	4 / 1 / 13	12 / 1 / 15	6 / 3 / 10	24 / 6 / 43	2 / 1 / 9	5 / 2 / 6	4 / 1 / 10	40 / 3 / 47	8 / 3 / 14	13 / 3 / 22	106 / 8 / 47	37 / 2 / 44	20 / 2 / 24
23180	1 / 1 / 2	12 / 2 / 24	6 / 2 / 9					10 / 4 / 20	42 / 9 / 64			7 / 2 / 14	50 / 3 / 56	16 / 3 / 24	18 / 4 / 20	79 / 4 / 42	66 / 5 / 78	39 / 3 / 46
24398	5 / 1 / 8	12 / 1 / 22	9 / 2 / 12					12 / 1 / 20	58 / 3 / 85		10 / 3 / 13	3 / 1 / 9	60 / 2 / 66	12 / 2 / 22	9 / 1 / 14	90 / 5 / 46	61 / 5 / 76	32 / 3 / 29
24760	0 / / 0	2 / 2 / 10	0 / / 0									6 / 2 / 13	24 / 2 / 28	11 / 2 / 19	12 / 3 / 20	68 / 7 / 32	15 / 2 / 15	4 / 3 / 9
141637	0 / / 0	0 / / 0	0 / / 0	6 / 2 / 14	5 / 2 / 11	2 / 1 / 4		3 / 1 / 7	4 / 1 / 8			0 / / 0	20 / 3 / 18	6 / 2 / 9	0 / / 0	76 / 5 / 37	20 / 2 / 13	1 / 1 / 8
143275	0 / / 0	2 / 1 / 7	0 / / 0	7 / 1 / 15	16 / 1 / 13	3 / 1 / 3	10 / 3 / 9	4 / 1 / 8	10 / 1 / 14	3 / 1 / 6	0 / / 0	0 / / 0	22 / 1 / 23	3 / 1 / 6	4 / 2 / 6	78 / 5 / 40	17 / 2 / 19	8 / 2 / 8
144217	2 / 1 / 7	2 / 1 / 3	2 / 2 / 6	13 / 2 / 27	20 / 1 / 16	5 / 1 / 8	28 / 5 / 20	4 / 1 / 10	13 / 1 / 23	5 / 1 / 6	5 / 1 / 6	5 / 1 / 6	52 / 2 / 50	7 / 1 / 12	9 / 3 / 8	157 / 8 / 77	18 / 3 / 23	7 / 2 / 8
144470	3 / 1 / 8	5 / 1 / 10	2 / 1 / 7	16 / 2 / 36	38 / 2 / 23	6 / 1 / 12	24 / 2 / 20	10 / 1 / 16	26 / 1 / 38	5 / 1 / 8	4 / 1 / 5	6 / 1 / 9	61 / 2 / 60	10 / 1 / 17	8 / 2 / 10	172 / 9 / 88	30 / 3 / 33	8 / 2 / 12
145502	3 / 1 / 7	6 / 1 / 11	2 / 1 / 4	14 / 1 / 33	28 / 3 / 21	7 / 1 / 11	19 / 2 / 17	10 / 1 / 16	29 / 2 / 46	4 / 1 / 6	3 / 1 / 6	6 / 1 / 10	62 / 3 / 53	11 / 2 / 17	11 / 2 / 12	164 / 8 / 85	38 / 3 / 35	13 / 2 / 17
147165	5 / 1 / 9	6 / 1 / 12	4 / 3 / 7	18 / 2 / 35	42 / 5 / 25	9 / 1 / 14	21 / 5 / 15	11 / 1 / 16	25 / 2 / 37	4 / 1 / 10	2 / 1 / 2	7 / 2 / 8	60 / 5 / 53	10 / 1 / 17	8 / 2 / 10	237 / 10 / 117	32 / 4 / 39	11 / 2 / 14
148184	2 / 1 / 5	7 / 2 / 13	8 / 2 / 9	14 / 2 / 23	25 / 3 / 18	8 / 3 / 12	16 / 3 / 13	10 / 1 / 17	27 / 3 / 41	3 / 1 / 6	7 / 2 / 11		43 / 2 / 40	10 / 1 / 13	7 / 2 / 6	96 / 7 / 53	51 / 4 / 53	29 / 4 / 38
149757		5 / 3 / 7	4 / 2 / 7	11 / 1 / 21	18 / 3 / 12	4 / 1 / 7	18 / 1 / 11	7 / 2 / 12	20 / 2 / 34	3 / 1 / 7	4 / 1 / 7	4 / 1 / 7	44 / 2 / 41	5 / 1 / 9	5 / 2 / 8	65 / 7 / 34	32 / 4 / 39	14 / 3 / 17
179406	4 / 1 / 10	14 / 2 / 27	5 / 2 / 15	22 / 1 / 52	25 / 5 / 20	10 / 1 / 20	40 / 5 / 30	16 / 3 / 30	62 / 2 / 100	7 / 2 / 18	15 / 2 / 19	4 / 2 / 16	108 / 3 / 109	20 / 1 / 39	13 / 3 / 24	156 / 8 / 84	78 / 5 / 95	36 / 4 / 39
183143	13 / 1 / 24	26 / 2 / 41	40 / 3 / 41	95 / / 146	250 / 10 / 142	24 / 2 / 36	220 / 10 / 143	52 / 6 / 65	116 / 7 / 162	24 / 2 / 41	25 / 2 / 33	50 / 3 / 51	350 / 5 / 318	88 / 5 / 119	53 / 2 / 57	783 / 12 / 342	234 / 10 / 225	73 / 5 / 75
184915	6 / 1 / 12	4 / 1 / 10	5 / 1 / 10	16 / 1 / 42	25 / 1 / 20	3 / 1 / 9	43 / 9 / 19	9 / 3 / 12	22 / 2 / 37	5 / 1 / 9	5 / 1 / 12	5 / 1 / 8	80 / 2 / 75	16 / 1 / 30	7 / 1 / 15	151 / 8 / 80	29 / 4 / 36	9 / 2 / 13
206165	7 / 1 / 15	12 / 1 / 22	13 / 1 / 15	27 / 1 / 59	60 / 4 / 40	8 / 2 / 14	56 / 10 / 38	21 / 4 / 26	71 / 2 / 86	9 / 1 / 18	10 / 2 / 13	12 / 2 / 13	106 / 2 / 107	21 / 1 / 33	14 / 2 / 25	204 / 7 / 97	88 / 5 / 96	33 / 3 / 39
206267	5 / 1 / 12	11 / 1 / 22	14 / 1 / 22	29 / 1 / 60	75 / 2 / 50	11 / 1 / 21	72 / 6 / 45	24 / 1 / 32	37 / 2 / 59	8 / 1 / 20	12 / 1 / 18	18 / 3 / 16	119 / 2 / 119	23 / 2 / 37	13 / 2 / 24	238 / 7 / 104	105 / 4 / 103	39 / 3 / 49
207198	8 / 2 / 13	22 / 1 / 39	16 / 2 / 21	33 / 1 / 70	76 / 3 / 49	16 / 3 / 28	58 / 9 / 40	30 / 11 / 34	80 / 3 / 127	10 / 1 / 19	16 / 1 / 24	32 / 1 / 23	122 / 2 / 127	22 / 2 / 38	15 / 3 / 23	252 / 6 / 111	152 / 6 / 161	73 / 4 / 89
208501	12 / 1 / 13	11 / 1 / 35	20 / 3 / 28	33 / 2 / 67	70 / 8 / 45	9 / 1 / 20	75 / 12 / 44	26 / 2 / 31	71 / 5 / 88	12 / 1 / 17	24 / 5 / 24	13 / 1 / 19	120 / 3 / 122	51 / 5 / 55	28 / 3 / 37	255 / 7 / 109	113 / 7 / 118	35 / 3 / 40
210839	11 / 2 / 13	12 / 1 / 25	17 / 3 / 23	34 / 2 / 75	69 / 10 / 41	8 / 1 / 16	96 / 5 / 57	25 / 3 / 38	62 / 1 / 93	12 / 2 / 20	20 / 4 / 18	15 / 1 / 18	146 / 2 / 147	25 / 1 / 43	21 / 1 / 33	248 / 7 / 118	79 / 7 / 102	26 / 3 / 30
216200	8 / 1 / 10	6 / 1 / 12	15 / 3 / 20	15 / 2 / 25	39 / 6 / 24		11 / 1 / 14		15 / 3 / 23	7 / 1 / 14	15 / 1 / 14	15 / 6 / 15	50 / 3 / 49	28 / 3 / 31	3 / 1 / 10	114 / 6 / 45	47 / 5 / 56	47 / 4 / 29
223128	6 / 1 / 11	9 / 1 / 20	7 / 1 / 13	16 / 1 / 39	40 / 3 / 28	10 / 1 / 10	30 / 1 / 24	21 / 1 / 24	54 / 2 / 79	7 / 1 / 13	10 / 1 / 16	7 / 1 / 13	65 / 4 / 66	19 / 1 / 31	10 / 1 / 20	112 / 6 / 60	52 / 5 / 65	17 / 3 / 30

Table 1. Measured strengths of DIBs in the McDonald data. HD numbers for target stars are given in the first column. The first row of the table contains the names of DIBs (their approximate positions). Individual cells contain subsequently (going from the top): equivalent width (EW), roughly estimated measuring error for EW (EW and its error are given in milliangstroms) and line depth, given in promilles of the local continuum level. Empty cells in the table indicate to the cases of very bad quality spectrograms.

2 OBSERVATIONAL MATERIAL

All the spectra analysed for the purpose of this paper were taken from the archives of Prof. Jacek Krełowski (Astronomical Center, Nicolaus Copernicus University, Toruń, Poland). We used spectra taken with the Canada-France-Hawaii Telescope (CFHT) (described by Snow and Seab (1991)) covering the spectral range 5780-5905 Å and spectra acquired at the McDonald Observatory with an echelle spectrograph fed with the 2.1 m telescope, covering the spectral range from 5600 to 7000 Å (Krełowski and Sneden, 1993). Spectra acquired with the CFHT have S/N of about 800 and resolution R of about 60000. The relatively high quality of the observational data used allowed us to measure the equivalent widths for many strong and weak DIBs.

3 MEASUREMENTS

Firstly, from the McDonald Observatory data, spectrograms of the highest possible quality were selected for 25 targets. Using the chosen spectra, we measured equivalent widths (EW) end depths of 18 prominent DIBs within the spectral range from 5760 to 6700 Å. HD numbers of stars and designations of considered DIBs, as well as values of measured parameters are given in Table 1. In each cell of the table (provided it is not empty) we have (from top to bottom): EW (in milliangstroms), error of the measurement of the EW, and line depth (in promilles of continuum). In the cases of problematic measurements, due to unsatisfactory quality of spectra, the cell in the table was left empty.

We have also selected spectra (McDonald) covering spectral range from 5750 to 5860 Å for 74 stars and we have measured EWs for 11 WDIBs (listed in Table 2) as well as for three well known and relatively strong DIBs, namely 5780, 5797 and 5849. Results of the measurements are given in Table 3. Empty cells in the table correspond to situations where the measuring procedure was impossible to carry out. Errors for EWs in the case of WDIBs are of course large and in many cases they correspond to the measurement value.

Positions of WDIBs given in Table 2 were measured in a spectrogram which was averaged over 48 stars (in the case of 5760 and 5763 averaging was over 3 stars) observed with CFHT. Before performing the averaging procedure, all points in individual spectra were shifted along the λ-axis a value $\Delta\lambda$ ($\Delta\lambda/\lambda = const$) calculated in such a way that the position of the interstellar NaI D2 line became the same as in laboratory ($\lambda = 5889.95$). All measurements were carried out by one of the authors (BW) and by using the same measuring procedure in all cases. The averaged spectrum compared with the single spectrum of star HD147165 is shown on Fig.1.

4 SEARCHING THE WDIBS

The reality of the considered WDIBs and their interstellar origin were checked carefully long ago by one of the authors (BW) and then it was also claimed by other authors (e.g. Krełowski and Sneden 1993, Galazutdinow et.al. 2000). The routine tests usually used to prove the interstellar origin of the absorption lines were described in the quoted papers in detail. Here we focus our attention only on positions and rough profile characteristics of WDIBs considered.

The knowledge of WDIB profiles is of fundamental importance; firstly, because we need their shapes to measure EWs more precisely, and secondly, to make spectroscopic investigations easier (mainly the comparisons with laboratory spectra of different molecular samples). To study the WDIB profiles one needs spectrograms of very high resolutions as well as high S/N ratios. Unfortunately, our data are not as good as required for such a purpose. To gain higher S/N ratio in the spectral range occupied by considered WDIBs we have averaged CFHT spectra over different stars. Averaged spectra obtained are displayed on Figure 1. Using these spectra we have measured positions of the WDIBs (Table 2). Measurements of the EWs for WDIBs were carried out keeping in mind their profile characteristics, visible in Figure 1. Profile characteristics visible in averaged spectrum were helpfull during EW measuring procedure for WDIBs in individual spectra with unresolved left and right limits of the profile.

5 STATISTICAL ANALYSIS FOR STRONG DIBS

As far as relatively strong bands are concerned we have analysed statistically mutual dependence between EWs, and separately between depths, for 18 prominent DIBs (data from Table 1). Because all considered bands are very far from being saturated, the members of one spectroscopic family should be linearly correlated.

One of the most important tests giving information about linear dependence between two variables is the test for the existence of linear correlation between these variables. Therefore, we obtained coefficients of linear correlation r, for all considered pairs of bands.

Results of the study of EWs and depths for 18 prominent DIBs are given in Table 4. Preliminary analysis show that all prominent DIBs are mutually dependent. Thus, during our search for possible spectroscopic families, we should concentrate on the cases of extremely high correlations. Marks in Table 4 were put only for these cases of correlation for which the value of statistic t (see Brandt 1970):

$$t = \frac{R}{\sqrt{1-R^2}}\sqrt{n-2} \qquad ,$$

(where R is a value of the parameter of the linear correlation obtained during estimation) distributed according to Student distribution with $n-2$ degrees of freedom, was twice as much as that obtained for the confidence level 0.995.

Theoretically on the basis of results contained in Table 4 we would be able to select some DIB families. However, by inspection of Table 4, we find for example, that the 6196 band has in its family also the following bands: 6203, 6270, 6426, 6614, 6699, 5780, 5797. But the 5780 and 5797 bands do not belong to the same spectroscopic family as was shown by Krełowski and Westerlund (1988). This indicates clearly that DIBs could be quite well correlated even if they do not belong to the same spectroscopic family, and that we cannot rely only on a formal statistical approach when looking for such families of DIBs. It is very probable that abundances of different agents of DIBs are relatively well correlated only
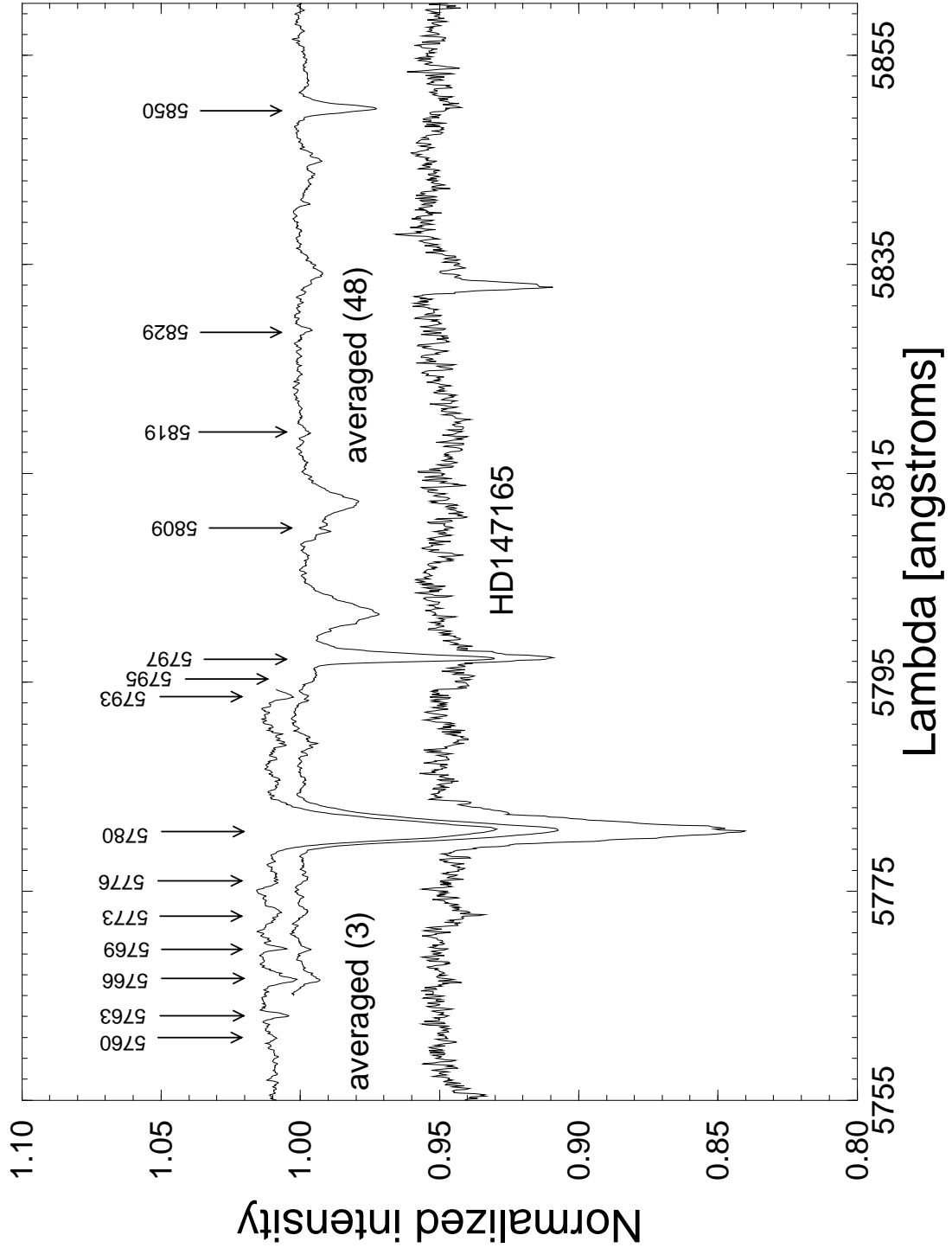
Figure 1. Averaged (over different stars) CFHT spectrograms. Vertical arrows indicate positions of studied bands. The shorter piece of spectrogram is a result of averaging over 3 stars (but these spectrograms were of the highest signal to noisy (S/N) ratios) whereas the longer one gives an average over 48 spectrograms of moderate S/N ratios. Spectrograms used in the averaging procedure look like this one for HD147165, given here for comparison.

WDIB's Name	Position [Å]	Position [cm^{-1}]
5760	5760.39	17359.94
5763	5762.72	17352.92
5766	5766.08	17342.80
5769	5769.11	17333.70
5773	5772.58	17323.28
5776	5775.87	17313.41
5793	5793.19	17261.65
5795	5795.11	17255.93
5809	5809.27	17213.87
5819	5818.75	17185.82
5829	5828.52	17157.01

Table 2. The list of names and exact positions for WDIBs. Positions were measured in averaged spectra (Fig.1) and their errors, in most cases, should be less than 0.1 Å.

due to properties of interstellar matter. Physical conditions which allow one molecule to be formed within interstellar clouds simultaneously may give a chance for the other ones to also originate. In such cases certain noisy correlation has to appear.

6 LOOKING FOR CORRELATIONS BETWEEN WDIBS AND 5780 AND 5797

The extremely low EWs of WDIBs (in most cases less than 10 mÅ) make their measurements very difficult. Avoiding large errors in the measured parameters is impossible. In such a case one looks for an adequate method to find any possible correlations between individual WDIBs and chosen strong DIBs. As it was shown in section 5, statistical correlations do not always give us entirely satisfying results even if the considered bands are relatively strong. As already mentioned, 5780 and 5797 bands do not belong to the same spectroscopic family (Krełowski and Westerlund 1988). Each of these strong bands may therefore play a role of a representative band for its own family and may have its "relatives" among WDIBs.

6.1 Statistical analysis of the intercorrelations between WDIBs and prominent DIBs

We have analysed statistically mutual dependence between strong and weak DIBs (data from Table 3). In some cases we obtained from measurements value zero or had a lack of measurements for WDIBs. We excluded all such cases from the analysis. Computed coefficients of linear correlation between EWs of each of the three strong bands (5780, 5797, 5850) and EWs of WDIBs are presented in Table 5. In all cases (with only one exception 5780 versus 5769) the parameter of linear correlation r is greater than zero at a high significance level (for level of confidence 0.95 the critical value of $r = 0.23$). This means that EWs of each of the strong bands are mutually dependent (in the statistical sense) and correlated. However, it should be noted that in some cases, even if the value of the parameter r is high enough according to our criteria, the χ^2 test suggests that a more complex dependence, rather than the linear one, may be relevant. From the detailed analysis we obtained: (i) WDIBs 5760, 5763, 5809, 5819 are linearly-dependent with all considered strong bands, as was checked using the χ^2 test, (ii) in the case of strong bands 5797 and 5850 we can also accept the

hypothesis of the linear regression fit for the 5793 and 5829 WDIBs, contrary to the strong band 5780 for which such hypothesis does not work, (iii) for the other bands (i.e. 5766, 5769, 5773, 5776 and 5795) the hypothesis of linear dependence with all considered strong bands should be rejected.

The result in point (i) clearly shows that some of the WDIBs are linearly well correlated with different DIBs (5780, 5797) which definitively do not belong to the same spectroscopic family. Therefore, the statistical approach to our data is not sufficiently strong by itself to discriminate the membership of WDIBs into families. More detailed analysis, taking into account other methods, is therefore required.

6.2 Averaging EWs method

To check mutual dependence between WDIBs and 5780 and 5797 bands, we have started from the following procedure. From Table 3 we extracted a sample with EW(5797) restricted to a very narrow range of values. From such a sample we separated two subsamples: the first one with relatively low, and the second one with relatively high values of EW(5780). In these subsamples we calculated mean values of EW(5780), EW(5797) and EWs for WDIBs. Both subsamples, as well as results of averaging, are displayed in Table 6. WDIBs correlated with 5780 should follow changes in EW(5780), contrary to those which are not correlated.

In a quite similar way we have extracted a sample of stars with almost constant EW(5780) and separated subsamples with opposite values of EW(5797) - Table 7. Such a simple procedure allowed us to divide WDIBs into three groups; (i) well correlated with 5780 (5776, 5795), (ii) well correlated with 5797 (5793, 5819, 5829) and (iii) correlated with neither 5780 nor 5797 (5769, 5773, 5809). Three other cases (5760, 5763, 5766) are rather complicated because they seem to be correlated with 5797 as well as with 5780. The main selection criterion here was a gradient of the average value for WDIBs. If this gradient, for a considered WDIB, is evidently similar to the gradient which is typical for the leading band (in our case this gradient is very close to 0.5) we included this WDIB into the family.

Please note that the term "correlation" used above does not mean the same as correlation in the statistical sense. Statistically, all considered bands are quite well mutually correlated.

line HD	5780	5797	5850	5760	5763	5766	5769	5773	5776	5793	5795	5809	5819	5829
2905	301	88	20	3	2	9	3	7	7	3	5	3	3	
10516	62	11	4	2	1	2	2	2	1	1	2	3	1	6
12953	282	79	38	4	3	7	6	6	7	6	8	5	5	6
13267	275	69	23	6	3	4	4	7	8	6	8	4	9	3
14134	277	77	25			16	7	12	15			5	5	6
14143	293	108	35				3	5	1	1	1	4	5	9
14489	274	77	24	3	5	6	6	8	8	6	18			3
20041	463	129	43	3	6	14	7	10	9	3	4	4	5	5
21291	200	74	25	3	4	8	7	5	5	5	5	4	10	6
21389	413	99	26	5	3	10	4	11	8	6	16	10	9	3
21483	147	82	32			13	6	2	0	7	9	4	3	7
22951	106	37	20	3	4	5	4	4	2	4	5	2	6	6
23180	79	66	39	3	6	10	10	3	3	6	4	4	4	4
24398	90	61	32	2	5	5	4	4	4	8	3	3	5	5
24432	350	112	34			7	3	4	3	8	9			
24534	86	62	22	5	9	15	18	18	15	15	6	8	2	9
24760	68	15	4	2	2	1	5	3	2	0	2	0		5
24912	194	50	23	2	4	10	3	5	8	2	4			6
27778	71	40	7	1	5	6	4	4	3	5	3	1	3	5
29309	222	91	37			11	2	2	5	10	7	2	4	7
34078	186	67	27	3	2	5	6		8	5	6	7	4	6
41117	351	127	56	4	7	5	4	14	9	8	6	7	5	10
42087	255	100	49	5	5		7		7	7	5	3		6
43384	455	136	48	4	4	7	3	9	4	11	15	5	6	6
47129	168	64	15	2	3		2	6	4	3		9	2	3
54662	195	49	29	3		9	5		6	7	4	3	7	2
89353	36	17	1	1	1	3	2	2	1	5	2	1	2	5
141637	76	20	1	2	1	4	1	3	3	0	0	1	2	2
142114	65	9	1	1	1	1	1	2	2	1	1	1	1	2
142184	65	20	7	1	0	2	2	7	5	1	3	3	2	1
143275	78	17	8	1	1	2	1	3	2	1	2	1	1	1
144217	157	18	7		2	3	0	3	4	1	4	2	2	1
144470	172	30	8	1	1	3	1	6	3	2	3	4	3	2
145502	164	38	13	1	3	7	3	9	6	3	5	4	2	3
147165	237	32	11		2	10			5	2	6	6	2	1
147889	347	154	77			19	25	19	10	22		9	8	16
147933	200	57	33	7	8	9	9	8	7	5	5	6	3	7
148184	96	51	29	1	3	8	8			3	2		2	5
149757	65	32	14	2	3	4	3	3	2	2	1	1	1	2
151804	219	36	14			8	2	4	6	1	1	2	2	
152408	278	43	21					9	4	5	5	3	1	2
154368	212	109	50	5	7	17	4	12	6	9	4	8	3	13
154445	192	63	24	3	4	9	4	5	3	4	1		2	5
164402	170	55	15	3		7	2	12	10			1	2	2
166937	277	71	27	3	5	14				5	9	9	12	7
167263	280	72	28			12	10	11	6			2	2	3
167264	227	81	41			14	6	6	4	6	1	4	4	4
169454	461	149	63			19	7	12	11	7	5	14	4	13
179406	156	78	36	1	6	8	8	2	6	8	6	6	3	7
183143	783	234	73	6	8	30	4	29	20	11	12	29	15	18
184915	151	29	9	1	1	6	1	2	6	2	3	4	0	2
192639	289	73	29			3	2		1	8	8	3	2	5
193322	167	64	21					2		3	5	2	2	5
193327	223	71	25	1	1		2	4		8	6	14	11	
193443	302	56	26			13	10	15	10	4	7		4	
198478	314	90	37	4	4	1	1	6	5	4				6
199579	111	55	14	2	2	9	6	6	4	5	4	2		
200120	26	7	1	2	2	0	1	1	2			3	3	2
202904	34	4	1	1	1	1	1	2	5	1	1	2	2	3
203064	162	71	18	2	2	7	4	4	5	2	2	1	1	3
206165	204	88	33	2	3	6	5	5	4	4	3	6	7	6
206267	238	105	39	3	5	15	8	8	6	6	4	3	3	4
207198	252	152	73	7	9	22	11	12	7	13	6		7	13
207260	310	111	32		7	11	8	9	7	7	7	8	5	8
208501	255	113	35	4	6	9	5			7	6	8	12	8
209481	178	70	21	1	2	5	5	5	3	5	3	3	1	4
209975	264	85	28	2	2	14			4	5	4	4	5	4
210839	248	79	26	2	4	11	4	7	4	4			5	4
212076	15	11	1	1	2	1	2	1	1	1	1	2	2	1
213420	85	31	14	2	5	5		2	3	2	1	4		3
214680	49	11	1			3	2		3	2	3	2	1	3
216200	114	47	47		5			15				3		9
218376	108	46	17	3	4	4	2	4	2	2	2	2	3	1
223128	112	52	17	4	5	6	1			6	3	4	12	5

Table 3. Measured EWs (in mÅ) for WDIBs listed in Table 2 and for three prominent bands - 5780, 5797 and 5850. Empty cells correspond to cases of quality of spectrograms too bad to find any weak band. Zero values were put in for non-remarkable bands in spectrograms of quite good quality.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
6065	1		x	x +	x				x +	x	x +			x	x	x	x	x	
6090	2	x		x	x +		x *		x	x *	+	x		x				x *	x +
6113	3	x +	x		x +	+	x		x +		x +			x	x +			x +	
6196	4	x	x +	x +		x *		x *	x +	x	x *		x +	x *	x +	x *	x *	x *	
6203	5			x +	x *			x +	+		x +		x +	x +	x		+	x +	
6234	6		x *	x					x +	+				x				x +	x
6270	7				x *	x +			x +		x +			x	x *	x		+	x +
6376	8	x +	x	x +	x +	+	x +	x +		x +	x +	x +	x +	x +	x +	x +	x +	x +	
6379	9	x	x *		x			+	x +		+			x	x +			x +	x
6426	10	x +	+	x +	x *	x +		x +	x +	+		x +	x	x +	x	x	x	x +	
6439	11		x						x +		x +				x			+	
6521	12				x +	x +	x	x	x +	x	x			x +	x		x +	x +	
6614	13	x	x	x	x *	x +		x *	x +	x +	x +		x +		x +	x +	x *	x +	
6661	14	x		x +	x +	x		x	x +		x	x	x	x +		x +	x	x	
6699	15	x			x *	+		+	x +		x			x +	x +		+	x	
5780	16	x			x *	x +		x +	x +		x		x +	x *	x		+		
5797	17	x	x *	x +	x *	x +	x +		x +	x +	x +	+	x +	x +	x	x			x +
5850	18		x +				x			x								x +	

Table 4. Line-line correlations between prominent DIBs listed in Table 1. The sign "+" means that EWs of considered lines are well correlated, with the value of coefficient of linear correlation, r, greater than 0.77. When this coefficient is greater than 0.9 the sign "*" is used. The sign "X" stands for good correlation ($r > 0.79$) between the depths of bands.

	5780	5797	5850
5760	0.36	0.54	0.52
5763	0.24	0.55	0.61
5766	0.67	0.79	0.74
5769	0.22	0.48	0.58
5773	0.69	0.70	0.66
5776	0.67	0.59	0.50
5793	0.49	0.76	0.81
5795	0.63	0.53	0.40
5809	0.68	0.68	0.55
5819	0.56	0.61	0.49
5829	0.51	0.77	0.84

Table 5. The correlation table between strong DIBs (listed in the first row of the table) and WDIBs (listed in the first column of the table). Formal coefficients of linear correlation were calculated on the basis of the data taken from Table 3.

6.3 Investigating the figures with arranged spectrograms

Another way to divide WDIBs into the three above mentioned groups consists in visual inspection of spectrograms. If we compose sequences of spectrograms in such a way that EW(5780), for example, is constant and EW(5797) gradually increases (Fig.2) we are able, after visual inspection of the picture, to indicate WDIBs which follow, and those ones which do not follow, the behaviour of 5797. Figure 3 shows the case of nearly constant EW(5797) and changing EW(5780).

This inspection procedure of Figures 2 and 3 confirms results achieved with the earlier described averaging procedure. Furthermore, one can, when studying Figures 2 and 3, make the following conclusions:

- the 5850 band, which corresponds to relatively strong phenomena, is very well correlated with the 5797 band and not (at all) with the 5780 one (this was claimed already by Krełowski *et al.*, 1993),

HD	5780	5797	5760	5763	5766	5769	5773	5776	5793	5795	5809	5819	5829
24912	194	50	2	4	10	3	5	8	2	4	-	-	6
54662	195	49	3	-	9	5	-	6	7	4	3	7	2
147933	200	57	7	8	9	9	8	7	5	5	6	3	7
164402	170	55	3	-	7	2	12	10	-	-	1	2	2
193443	302	56	-	-	13	10	15	10	4	7	-	4	-
mean value in the group	212.2	53.4	3.75	6	9.6	5.8	10	8.2	4.5	5	3.33	4	4.25
148184	96	51	1	3	8	8	-	-	3	2	-	2	5
199579	111	55	2	2	9	6	6	4	5	4	2	-	-
216200	114	47	-	5	-	-	15	-	-	-	3	-	9
218376	108	46	3	4	4	2	4	2	2	2	2	3	1
223128	112	52	4	5	6	1	-	-	6	3	4	12	5
mean value in the group	108.2	50.2	2.5	3.8	6.75	4.25	8.67	3	4	2.75	2.75	5.67	5
very probable correlation with 5780								+		+			

Table 6. Two subsamples of stars chosen in such a way that average EW(5797) is almost constant in both subsamples, contrary to EW(5780) which in the first subsample is almost twice as large as in the second one. The names of bands are listed in the first row, whereas names of target stars used are given in the first column of the table. In both subsamples for each band the mean value of measured EWs was counted. The sign "-" stands for the lack of the data and "+" indicates interesting examples of correlation (see text).

HD	5780	5797	5760	5763	5766	5769	5773	5776	5793	5795	5809	5819	5829
42087	255	100	5	5	-	7	-	7	7	5	3	-	6
206267	238	105	3	5	15	8	8	6	6	4	3	4	4
207198	252	152	7	9	22	11	12	7	13	6	-	7	12
208501	255	113	4	6	9	5	-	-	7	6	8	11	8
mean value in the group	250	117.5	4.75	6.25	15.33	7.75	10	6.67	8.25	5.25	4.67	7.33	7.5
13267	275	69	6	3	4	-	7	8	6	8	4	9	3
14134	277	77	-	-	16	7	12	15	-	-	5	5	6
14489	274	77	3	5	6	6	8	8	6	-	-	-	3
147165	237	32	-	2	10	-	-	5	2	6	6	2	1
152408	278	43	-	-	-	-	9	4	5	5	3	1	2
166937	277	71	3	5	14	-	-	-	5	9	9	12	7
167263	280	72	-	-	12	10	11	6	-	-	2	2	3
mean value in the group	271.14	63	4	3.75	10.33	7.67	9.4	7.67	4.8	7	4.83	5.17	3.29
very probable correlation with 5797									+			+	+

Table 7. The same as in Table 6 but here the mean EW(5780) is rather stable whereas EW(5797) drops almost in half when going from the first subsample to the second one.
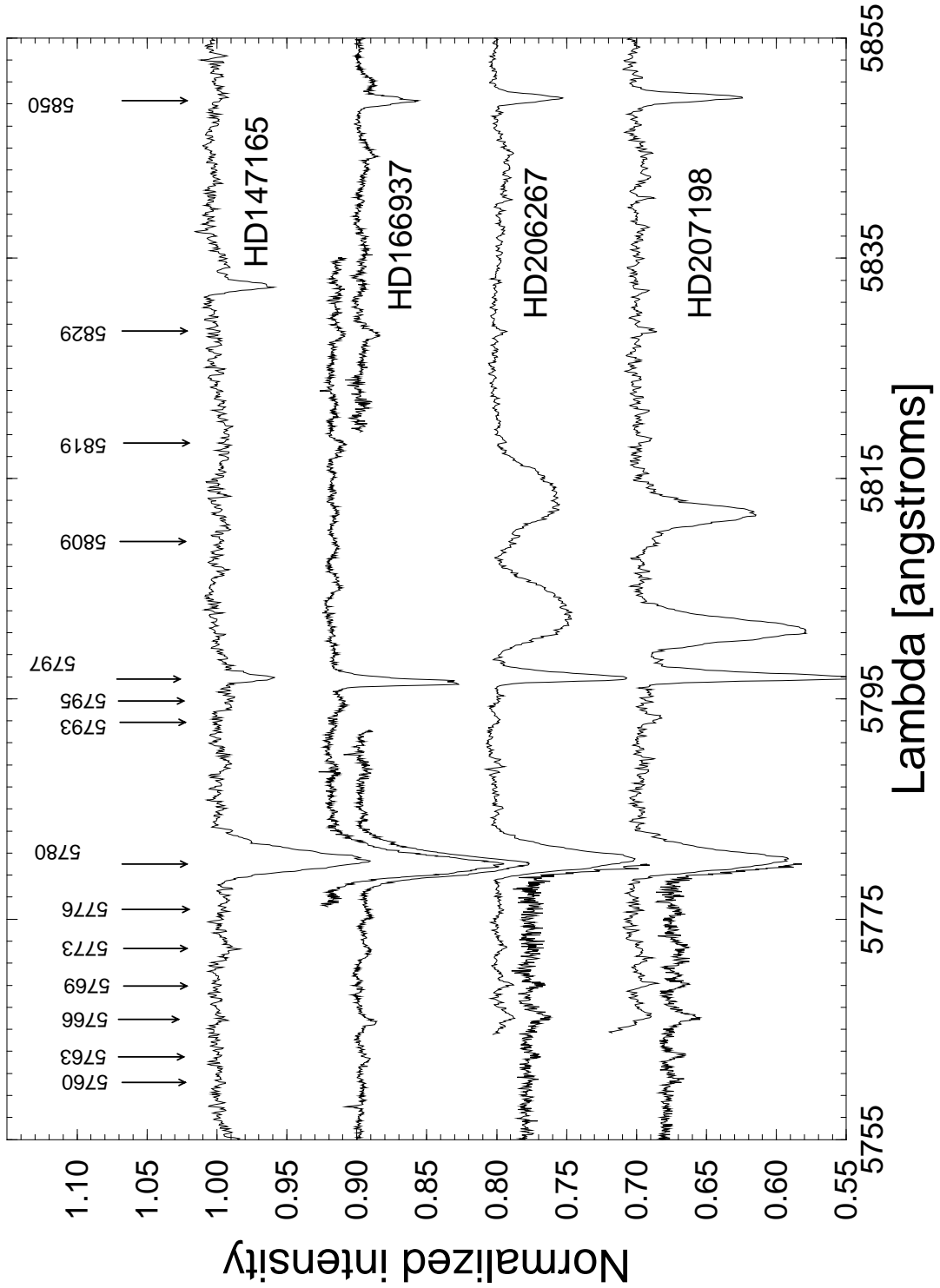
Figure 2. CFHT (the longest pieces) and McDonald's (shorter, individual orders of echelle spectrograph) spectrograms arranged in such a way that strength of 5797 band gradually increases whereas intensity of 5780 band remains constant.
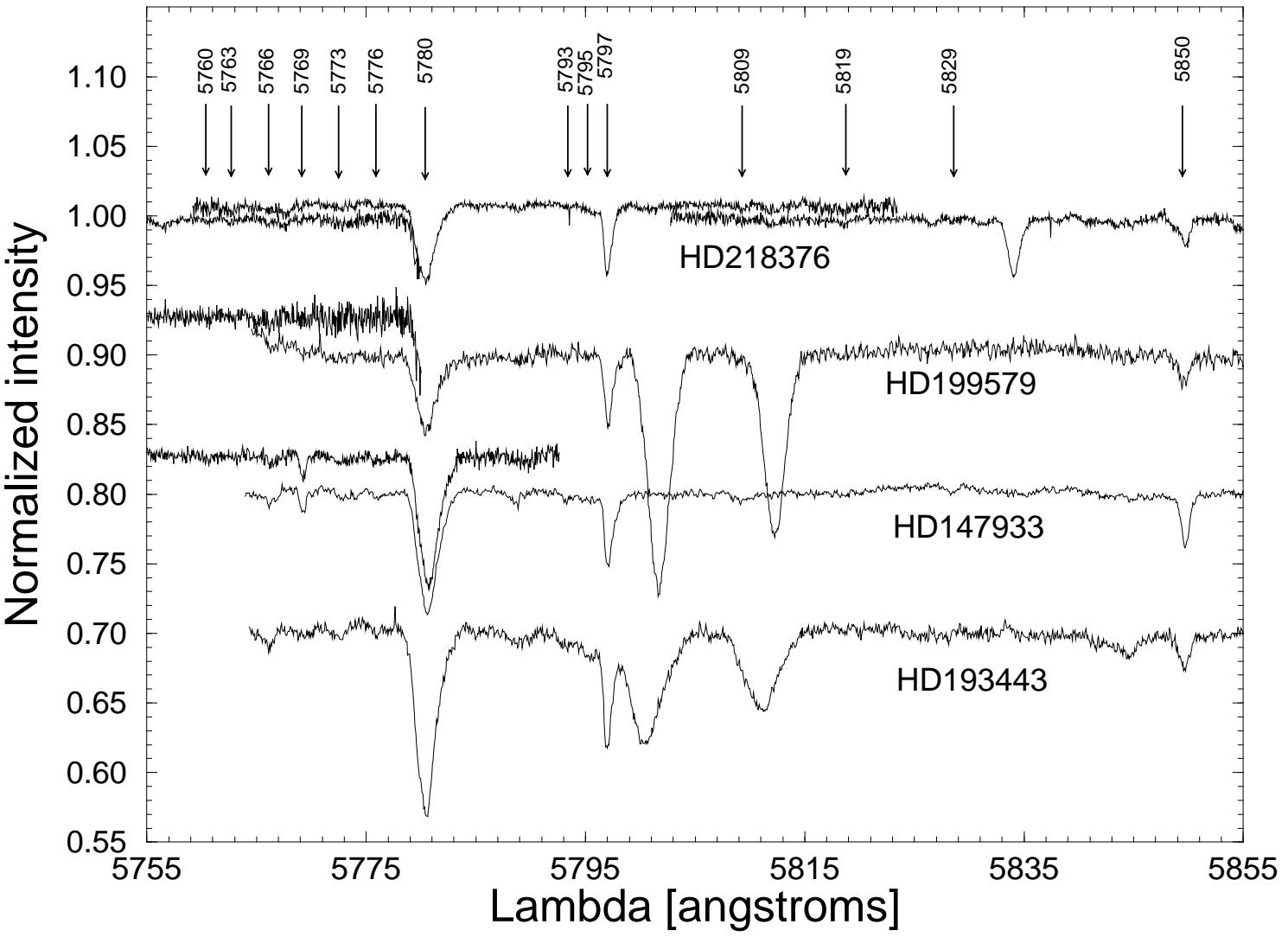
Figure 3. Similar to Figure 2, but here the roles of 5780 and 5797 bands are exchanged. Intensity of the first band increases whereas the strength of the second one remains constant.

- the 5763 band follows the behaviour of the band 5797 and does not follow (at all) the 5780 band,

- although Figures 2 and 3 are not as good as required for studying the 5760 band it seems that this WDIB is correlated rather with 5797 than with the 5780 band,

- the 5769 band also seems to be well correlated with the 5797 band.

It is worthly of note that the observations we are dealing with here were not planned for searching for spectroscopic families. One may, however, perform much more adequate observations, directed to the subject. In the case of better data, similar analysis would give much more reliable results and lead directly to separation of true spectroscopic families of bands.

7   DISCUSSION

As mentioned in the introductory section, the main obstacle to isolating spectroscopic families of DIBs is the noisy correlation. Due to a very high level (as the analysed data reveals) of noisy correlation in the considered data, the ability of statistical method to isolate spectroscopic families are very limited.

Tight linear correlation, expected between members of the same spectroscopic family, is efectively hidden by noisy correlation and by measuring errors. This is evident when we study results of statistical analysis described in the previous section. Looking at Table 5 only, we are not able to indicate which WDIB belongs to the same spectroscopic family as, for example, the band 5797. On the other hand, when considering Table 4, we would be inclined to isolate, e.g, the family of strong lines: 6196, 6203, 6270, 6426, 6614, 6699, 5780, 5797; and this would be a mistake, since 5780 and 5797 belong to different families, as mentioned in section 5.

Taking into account that statistical analysis requires plenty of usable data and gives insufficient (for solving our problem by itself) results, it is therefore not recommended as an appropriate tool for isolating spectroscopic families. [However, the statistical approach may be useful to distinguish linearly correlated bands from these ones which are correlated non-linearly. Non-linearly correlated DIBs should belong to different spectroscopic families. Also multidimensional statistical analysis could be useful in this case. Further study of this problem will be the subject of a separate paper (Godłowski & Wszołek, in preparation)].

Methods described in subsections 6.2 and 6.3 are much more appropriate than the formal statistical aproach. They need a fewer number of spectrograms and much less time for making EW (or depth) measurements. These methods seem also to give valuable results. Using these methods we performed preliminary separation of two presumable spectroscopic families: (i) 5780, 5776 and 5795, and (ii) 5793, 5797, 5819, 5829 and 5850.

Most probably, designated families are not complete yet. One cannot exclude also the possibility that we made wrong indications. In the case of almost constant ratios between column densities of various DIB carriers in interstellar clouds, we have a chance to get results quite similar those of the case when we have to deal with few spectral lines of the same carrier. Further investigation, based on better data

samples and involving other spectral ranges, is necessary to isolate true spectroscopic families of bands.

ACKNOWLEDGEMENT

REFERENCES

Brandt S., 1970, Statistical and Computational Methods in Data Analysis. Nord Holland Publishing Company

Chlewicki G.,van der Zwet G.P.,van Ijzendoorn L.J.,Greenberg J.M., 1986, ApJ. 305,455

Galazutdinow G.A.,Musaev F.A.,Krełowski J., Walker G.A.H., 2000, PASP,112,648

Herbig G.H.,1995, Ann.Rev.Astron.Astrophys. 33,19

Josafatson K.,Snow T.P.,1987, ApJ. 319,436

Krełowski J.,Sneden C.,1993, PASP 105,1141

Krełowski J.,Snow T.P.,Papaj J.,Seab C.G.,Wszołek B.,1993, ApJ. 419,692

Krełowski J.,Walker G.A.H.,1987, ApJ. 312,860

Krełowski J.,Westerlund B.E.,1988, A&A. 190, 339

Snow T.P.,Seab C.G.,1991, ApJ. 382,189